

INDIUM

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All indium production in the United States during 2002 involved refining of lower grade imported indium metal and scrap recycling. Two refineries, one in New York and the other in Rhode Island, produced the majority of indium metal and indium compounds in 2002. A number of small companies produced specialty indium alloys and other indium products.

Domestic consumption in 2002 was estimated by the U.S. Geological Survey to have increased to about 85 metric tons (t). Estimated consumption by different sectors showed an increase in the application for coatings that was offset by the reduction in the uses for solder and alloys and for electrical components compared with 2001—coatings, 60%; solder and alloys, 20%; electrical components and semiconductors, 10%; and other uses, 10%. The value of indium consumption in the United States in 2002 was about \$6.2 million at an average New York dealer price of \$73 per kilogram (\$2.30 per troy ounce), as calculated from prices published in Platts Metals Week.

World production in 2002 decreased by almost 14% from 2001 levels. The four major producing countries were Canada, China, France, and Japan. Minor primary production came from Belgium, Peru, and Russia. Recycling of indium scrap continued to increase, but not enough to offset the decline in primary production.

World consumption also decreased in 2002. This was due to a worldwide downturn in the markets for laptop computers and flat-screen monitors that use indium-tin oxide (ITO) coatings and the increased use of thin film technology, which requires less ITO per area of coating.

World reserves, which are based on estimated indium content of zinc reserves, are sufficient to meet anticipated demand for at least 10 years at levels slightly above current world consumption. This projection assumes that almost one-half of the world's indium supply will result from recycling of existing materials. Canada has the world's largest reserves at about 27% and the United States holds about 12% of world reserves.

Legislation and Government Programs

On the basis of the potential for substantial energy savings, various national governments have targeted solid-state technologies, which include light-emitting diodes (LEDs), for increased funding for research and development. A proposal for a program to fund solid-state lighting has received considerable support in the U.S. Congress, and Japan already has a program underway (Whitaker and Newey, 2003).

The U.S. Environmental Protection Agency (EPA) introduced a procedure for simplifying the removal of cathode ray tubes (CRTs) as a regional experiment at the end of December 2002. This recycling experiment was then stopped early in 2003 to allow further study on the recycling of electronic components. Advocacy groups argued that individual scrap yards would not be able to guarantee the material's final destiny when selling to brokers or larger yards. Much of the debate now hinges on the export of recyclable scrap to foreign entities that do not maintain adequate hazardous material dismantling facilities (Schaffer, 2003).

An estimated 37 t of indium is contained as flue dust at a site in Kellogg, Idaho, where Bunker Hill Company once operated a lead and zinc smelter (Platts Metals Week, 2001). Shortly after closure of the smelter, the EPA declared it to be a Superfund site under regulations that cover nonoperating sites with environmental problems, which require cleanup. Although some firms have bid on the cleanup of the smelter site, none have submitted a proposal that would fulfill the environmental requirements (Cami Grandinetti, U.S. Environmental Protection Agency, written commun., October 24, 2002).

Production

U.S. production of indium in 2002 consisted of raising the grade of imported indium to higher purity metal. Lower grade (99.97%) and standard-grade (99.99%) imported indium was refined to purities of up to 99.9999%. Indium Corporation of America, Utica, NY, and Arconium Specialty Alloys, Providence, RI (a division of N.V. Umicore, SA) accounted for the major share of U.S. production of indium metal and products.

Indium metal is produced in various forms (ingot, foil, powder, ribbon, wire, and others) as well as grades of purity. Many small companies produce high-purity indium alloys, compounds, solders, ITO coatings, and other indium products. Only small amounts of new indium scrap were recycled in 2002. This is because the infrastructure for collection of indium-containing products is not well established in the United States and because the low price of primary indium does not economically warrant its development.

Consumption

By far, indium metal's major use is for thin-film coatings on glass and liquid-crystal displays (LCDs). The use of ITO in organic LEDs and plasma displays are relatively small segments of the coating use but are expected to have strong growth during the next

several years (O'Neill, 2003). The use of indium in coating, which was mainly in the form of indium oxide and ITO, constituted nearly two-thirds of total domestic indium use in 2002.

Two kinds of coatings contain indium—conductive and infrared-reflective. LCDs for portable computer screens, television screens, video monitors, and watches, which were the major commercial applications, use electrically conductive coatings. These electrically conductive coatings are also used to defog aircraft and locomotive windshields and to keep glass doors on commercial refrigerators and freezers frost-free. Indium coating on window glass takes advantage of indium's infrared reflective properties and limits the transfer of radiant heat through the glass. This property of indium can be used to heat and cool buildings more efficiently.

The technologies of glass coatings and semiconductors have been the largest areas of research and development for indium during the past several years. Although coatings remained the most widespread use for indium, the production of electrical components and semiconductors is expected to be a major growth application for indium during the next several years.

About one-fifth of the indium consumed was used in combination with other metals to form low melting-point alloys and solders. The alloys are used in electrical fuses and fusible links and as gripping tools for the grinding of delicate materials. The advantages of indium-containing solders are that they have lower melting points, are more flexible over a wider temperature range, and inhibit the leaching of gold components in electronic apparatus.

Alkaline batteries combined with semiconductors and other electronic uses are also a fast growth segment of the indium market. This segment accounted for about 15% of the domestic indium use in 2002. The alkaline batteries used indium to prevent buildup of hydrogen gas within sealed battery casings.

Prices

The average New York dealer price, as reported by Platts Metals Week for 99.97% to 99.99% pure indium, decreased to \$68 per kilogram (\$2.10 per troy ounce) by midyear from \$78 per kilogram (\$2.41 per troy ounce) at the beginning of 2002. The price was maintained until the end of November when it began to climb and ended the year at an average of \$85 per kilogram (\$2.64 per troy ounce). According to Platts Metals Week, the published producer price remained constant throughout 2002 at \$159 per kilogram (\$4.95 per troy ounce) for Arconium and \$110 per kilogram (\$3.42 per troy ounce) for Indium Corporation of America—leading manufacturers and suppliers of refined indium products.

The decline of indium prices began in 1999 and continued through midyear 2002. Because indium is a byproduct of zinc concentrate processing, increases in zinc price that increase zinc supply will tend to increase the supply of indium. Indium's supply is affected by only those zinc smelters that have zinc concentrate feed that contains sufficient indium and the required processing facilities to recover indium. These two factors were not sufficiently influential until late in 2002.

Despite the use of indium for popular LCD flat-screens and products that employ flat-screen technology, a large supply/demand imbalance has developed because markets for these electronic applications remained stagnant during 2001 and 2002. Although the stagnant market conditions remained, a strong reduction in supply more than offset this weakened demand, and prices began to rise at the end of 2002.

Trade

U.S. imports of indium in 2002 increased by 41% (weight percent) to 112,000 kilograms (kg) but increased by only 1% in value compared with 2001 values. This was due to a combination of a reduction in contained metal and lower prices for the imported materials.

China, which was the largest source of U.S. indium imports in 2002, shipped 49,800 kg, which represented 45% of the total imported. It was followed, in declining order of importance as a source, by Canada, Russia, and Japan. Data on U.S. exports of indium were not available, but were estimated to have remained at 2001 levels of about 10 t.

World Review

Belgium.—N.V. Umicore SA's Venture Unit continued the development of indium phosphide (InP) substrates. A collaborative effort with the Polish Institute of Electronic Materials Technology resulted in the startup of a production line of InP substrates now being tested by customers. Arconium was integrated into Umicore's Thin Film Products Division and will be in charge of developing downstream markets for Umicore's indium business (N.V. Umicore SA, 2003). Umicore's production capacity for indium metal is approximately 30 metric tons per year (t/yr).

China.—Concentrate supplies that were left after mine closures following the Nandan mine disaster of 2001 were dwindling, and a shortfall was anticipated. Chinese authorities closed the mines in the Nandan area in response to several mine accidents. The mines will probably not reopen in fewer than 3 years, which could cause some indium producers to idle capacity for lack of indium-bearing concentrates.

Chinese indium output for 2002 reportedly declined by about 60 t to 139 t as the supply of raw material from the Guangxi Zhuang Autonomous Region became scarce late in 2001. Indium production was expected to continue falling through 2003 with a corresponding increase in price. Several ITO production lines, which had a total capacity of 85 t/yr, were recently or are being built in China (Antaike, 2003).

Despite the decrease of overall indium output, Huludao Zinc Smelter Co. expected to maintain its indium production in 2003 at 14 t,

which was the same level as that of 2002 (Platts Metals Week, 2003). Luizhou China Tin Group Co., Ltd. began construction of Huaxi's indium and zinc project at the Laibin smelter in March 2002 and expected to complete construction within 1 year (Antaika, 2002a). The company had expected to produce 35 t of refined indium in 2002 if certain technical problems with the leaching rate and removal of impurities from crude indium could be overcome (Antaika, 2002b).

Liuzhou Intai Technology Co. reorganized as Guangxi Intai Technology Co., Ltd. and continued to produce high-purity refined indium products. The company's production capacity is 40 t of 99.995% indium metal; and it also produces high-purity indium (99.999%, 99.9999%), indium chloride, indium hydroxide, indium nitrate, indium oxide, indium sheet, indium shot, indium sulphate, indium-tin alloy, ITO powder, and other indium products (Guangxi Intai Technology Co., Ltd., 2002§¹).

France.—Metaleurop SA's exit from primary zinc production at its Noyelles-Godault smelter has reduced worldwide indium supply by an estimated 55 t. The closing of this plant in November 2002 was a key factor in the firming of indium metals prices at the close of the year (Guerriere, 2003).

Japan.—Japanese imports of indium, ITO scrap, and recycled indium materials dropped by more than 30 t from 2001 levels to 140 t. Japan's imports of these materials from the United States during this same period almost tripled and levels increased by more than tenfold compared with those of 2000 and 1999. France and China reduced exports of these indium materials to Japan by 61% and 12%, respectively, in 2002 compared with those of 2001 (Roskill's Letter from Japan, 2003b).

Japanese production of new indium by Dowa Mining Co., Ltd. and Nippon Mining & Metals Co., Ltd. remained stable at between 50 and 55 metric tons per year for the past several years and continued to remain so in 2002. With the decline in Japanese zinc refining, an aggressive recycling program was expected to make up for any shortfalls in Japanese domestic production (Roskill's Letter from Japan, 2003c).

The Japan Electronics Industry Association estimated that the value of domestic output of electronic components and products dropped by 8% in 2002. During the next year, consumer electronics production is expected to rise by 4%; industrial communications equipment was expected to rise slightly; electronic devices, such as LEDs and semiconductors, could rise significantly; and output of CRTs for computers could drop by more than 10% (Roskill's Letter from Japan, 2003a).

Korea, Republic of.—Samsung Electronics Co., Ltd., which was ordering about 30 million LED chips per month from Taiwan at the end of 2002, was close to completing manufacturing facilities to ensure an internal supply of these LED chips (Whitaker and Newey, 2003). These facilities should complement the Gumi ITO nano powder manufacturing facilities completed in October 2002 by joint-venture affiliate Samsung Corning Co., Ltd. This new facility will supplement the Japanese powder imports for coating ITO thin films onto flat panel displays (FPD) (Samsung Corning Co., Ltd., 2002§).

Namibia.—ZincOx Resources plc announced a total tonnage of 2.9 million metric tons at its Tsumeb slag project. Check analyses at various laboratories indicate an indium grade of 170 parts per million. ZincOx expected to recover 75% of the indium by using Ausmelt technology; it also expected to recover additional values of gallium, germanium, and zinc. Work continued on confirmation of reserves, acquisition of bulk samples, and metallurgical testwork (ZincOx Resources plc, 2002§).

Taiwan.—In Taiwan, four established manufacturers emerged as leading suppliers of LEDs based on indium-gallium nitride (InGaN) technology. More than 10 additional manufacturers had the capability to make InGaN-based LEDs, and more than 80 InGaN metal organic chemical vapor deposition (MOCVD) reactors were located in the country (Compound Semiconductor, 2003a).

Current Research and Technology

A comprehensive reference work on indium geology and mineralogy entitled *Indium—Geology, Mineralogy, and Economics* was published in 2002. The authors present a petrologic and mineralogic framework for the investigation of indium metallogeny and discuss miscellaneous indium occurrences throughout the world. The work includes a brief summary of the economic aspects of indium production and use and closes with an extensive outline of the characteristic features of more than 100 indium-bearing deposits (Schwarz-Schampera and Herzig, 2002).

The study of materials for electronic components, which is certainly one of the most active areas of global research, has continued at a feverish pace. Some of the highlights of this research with potential for discovering new uses and thus increasing world demand for indium include a new nickel-ITO (Ni/ITO) coating compound, a new indium-gallium arsenide (InGaAs) laser diode, development of electronic devices to detect anthrax and other biological agents, and development of new InP technology.

Researchers in Taiwan have been studying Ni/ITO as a replacement for the conventional nickel-gold (Ni/Au) as an ohmic contact on p-contact gallium nitride. The results of their experiments show the Ni/Au to improve the transmittance of the contacts, to reduce the specific contact resistance, to maintain the forward voltage at 20 milli-amperes while increasing the power output, and to reduce the lifetime luminous intensity decay for LEDs constructed with these materials (Compound Semiconductor, 2003b).

Sanyo Electric of Japan developed a new InGaAs laser diode that it plans to produce in volume by mid-2003. This new chip can maintain a vertical structure with electrodes sited at the top and bottom of the device. The implantation of the device in the p-type cladding layer allows for greater optical and current confinement, thus stabilizing the layer and reducing noise (Pool, 2002).

Cree, Inc. (NC) was awarded \$14.5 million to develop LEDs and laser diodes to assist in the detection of anthrax and other biological agents. This funding comes from the U.S. Army Research Laboratory and forms part of a 4-year contract that totals \$26.5 million (Compound Semiconductor, 2002a).

InP represents another exciting area of growth for the semiconductor industry. Almost 130 companies and 100 universities

¹References that include a section mark (§) are found in the Internet References Cited section.

worldwide are working on electronics projects based on InP technology. The focus of this work has been related to integrated circuits for optical networks, mobile phones, and power amplifiers (Compound Semiconductor, 2002b).

InP has several advantages over established gallium arsenide (GaAs) semiconductor technology. InP-based amplifiers consume less power and improve battery life and reception. Continued research has increased InP line yields to match those of GaAs, and, because manufacturing technology is the same for both products, the need for increased investment to produce InP substrates is insignificant (Streit, 2002).

Outlook

Indium demand could easily reach 660 t by 2006 (Metal-Pages, 2003a§). Demand for industrial and consumer electronic goods, which are discretionary items, will, to a large extent, depend on world economic conditions. The use of ITO in thin film transistors for LCDs, FPDs, and the latest plasma display panels is increasing at an exponential rate, while the amount of ITO used per individual unit is being greatly reduced.

Forces that are driving the increased demand for ITO include the drastic reduction in prices for FPDs in recent years, the consumption of less electricity compared with traditional CRTs, and the increased ease of storage and transport for flat panel displays (Wilkinson, 2003).

A key issue on the supply side will be the ability of individual countries to recycle the indium-containing electronic components, which tend to have a short obsolescence cycle. Japan and other East Asian countries appear to be at the forefront of recycling efforts. Recent trends in indium price combined with the curtailment of primary refining capacity have added an extra incentive to the recovery of secondary indium. Sustained prices in the \$160 to \$200 per kilogram range will encourage increased recycling and primary production (Metal-Pages, 2003b§).

Additional impetus for increased consumption of indium comes from the semiconductor industry where the market share for InP has increased in such applications as lasers, photodiodes, and other optic telecommunications systems (Furukawa, 2000).

Indium prices should continue an upward trend as zinc mine closings affect the primary indium market. Zinc ore production is the main source of primary indium and, therefore, has a direct effect on indium supply. The languishing zinc market has forced many high-cost and low-grade underground mines and a few of the older and less efficient zinc refineries to close.

The contraction of zinc ore production has already firmed up the indium market. The indium content of most, if not all, zinc ore deposits does not provide sufficient return to impact the overall economics of the mining enterprise significantly. Recycling of indium could expand significantly in the United States if the price of indium continues to increase. About 60% of the ITO scrap could be reused should the price of indium warrant increased recycling.

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Ryan's Notes.

TABLE 1
U.S. IMPORTS FOR CONSUMPTION OF INDIUM, BY CLASS AND COUNTRY¹

Class and country	2001		2002	
	Quantity (kilograms)	Value (thousands)	Quantity (kilograms)	Value (thousands)
Unwrought and waste and scrap ² :				
Belgium	--	--	215	\$38
Canada	7,710	\$762	32,100	2,340
China	49,500	3,740	49,800	2,960
France	4,980	575	6,290	519
Germany	69	20	62	16
Italy	4	2	25	2
Japan	5,360	1,330	8,280	618
Peru	3,660	322	4,560	244
Russia	5,000	511	8,520	825
Singapore	278	90	63	13
Switzerland	2,650	259	1,360	87
United Kingdom	158	63	547	91
Total	79,400	7,670	112,000	7,750

-- Zero.

¹Data are rounded to no more than three significant digits; may not add to totals shown.

²Includes indium powder in 2002.

Source: U.S. Census Bureau.